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A PETROGRAPHICAL SKETCH OF ÆGINA AND METHANA.[1]

PART III.

Segregations.—Before taking up the discussion of the chemical composition of the rocks described in Part II. it will be well to describe a series of segregations (endogenous enclosures) found in them, so that their chemical composition, which is closely related to that of the enclosing rocks, may be discussed at the same time with that of the latter.

A few preliminary words may be allowed on the use of the term above given. The various forms of foreign matter that occur in rocks and minerals are of such common occurrence and so frequently referred to that the use of simple terms to denote the different occurrences seems advisable. Those suggested by Lacroix[2] seem to be the best possible, as well as consistent with the present usage of many petrographers. The term *inclusion* (Fr. *inclusion*) is reserved for foreign bodies in the component minerals of a rock which are derived from the same magma as the including mineral; *enclosure* (Fr. *enclave*) denotes fragments of foreign rock in eruptives, *e. g.*, such as have been torn away from the conduit walls; finally, *segregation* (Fr. *ségrégation*, Germ.

NOTE.—As the writer was unable to revise the proofs some errors have crept into the foregoing parts of this paper, and the following corrections must be made:

II. 789, line 18; 806, lines 29, 31; 807, line 17; III. 44, line 3, for "Kolautziki" *read* "Kolantziki."

II. 805, line 7, for "227–239 B.C." *read* "276–239 B.C."

II. 812, line 27, for "von Lubach" *read* "von Seebach."

III. 38, line 31, after "coast" *insert* "of Methana."

III. 40, lines 7, 32, for "Vesili" *read* "Vasili." H. S. W.

[1] Continued from page 46.

[2] A. LACROIX: Sur les enclaves acides des roches volcaniques d'Auvergne. Bull. d. services de la carte geol. de la France. No. 11, 1890, pp. 25–56. Ref. in Neu. Jahrb., 1892, I.,–67.

Ausscheidung) is reserved for the masses (whether isolated or in streaks) formed by the earlier crystallized or solidified portions of the molten magma. The above distinction between "inclusion" and "enclosure" was proposed by me in a paper on the basalts of Kula in 1894;[1] and it will be seen that "enclosure" corresponds to the generally used term "*exogenous* enclosure," while "segregation" answers to the longer "*endogenous* enclosure." The term "segregation" is preferable to "aggregation," "concretion," or "secretion" since the last three are all in general use with well marked connoted meanings.

In almost all the eruptive rocks of the region, with the exceptions of the biotite-dacite of Kolantziki, and the hypersthene-andesites of Oros and Chelona, there are seen spots and patches which differ in color and structure very decidedly from that of the surrounding rock. In the great majority of cases these are irregularly rounded, some, as at Kakoperato and at the hillock in the plain east of Mt. Chelona, roughly spherical or spheroidal, and only in a very few cases subangular. The line of demarkation between them and the surrounding rocks is very sharp, and they vary in size from that of a pea to that of one's head. Since, as will be seen later, these have much the same mineralogical composition as that of the enclosing rock (though differing in structural and chemical characters) they must be regarded as true segregations—the products of an early differentiation and partial solidification of the magma at a presumably great depth, which have been brought to the surface as unmelted remains of still larger masses by the erupted lava stream. Such segregations are not uncommon elsewhere, but the nearest parallel to these here described are those found by Küch[2] in the Colombian andesites and dacites, as well as those in Ecuadorian lavas described by Belowsky,[3] both of whose papers are occasionally referred to.

These segregations are, megascopically, chiefly characterized by a fine, but even, granular structure made up of hornblende and

[1] Am. Jour. Sci. XLVII, 1894, p. 115.

[2] KÜCH, op. cit. pp. 82–84.

[3] BELOWSKY, op. cit. pp. 57–60.

plagioclase crystals, and rather dark gray color which on weathering becomes a pinkish brown. Exceptions to this general structure are found in the segregations of the Kaimeni stream, and in one from Mt. Gaiapha, which are much larger grained and look like medium-grained diorites. They carry few phenocrysts though some are seen in almost all the specimens, in most cases of white plagioclase and more rarely of short, black hornblende prisms. The Kaimeni segregations also show several clear, colorless quartz grains with no augite rings, and those from Kakoperato some pinkish quartzes of larger size and surrounded by a narrow ring of green augite.

Under the microscope it is seen that the segregations show in general the same mineral composition as their enclosing rock, except that no quartz was found in the slides, even in those of the dacites rich in quartz. We can distinguish in the sixteen specimens examined two distinct varieties which differ considerably in structural and in mineralogical characters; first with the mineralogical composition of hornblende-augite-andesite, which are found in the rocks of Mts. Pagoni and Gaiapha and presumably also in those of Mt. Chondos, and secondly, hornblende-andesite segregations from the andesite of Kaimeni and the dacites of Anzeiou, Kakoperato and the neighborhood of Kosona.

The first variety has a peculiar porphyritic structure of which the groundmass is not abundant, and is analogous to the mesostasis of some melaphyres. It is quite trachytic in appearance, being composed of colorless plagioclase lathes and leptomorphic grains, with many twinning lamellæ, some of which gave extinction angles of about 15°. No flow structure was noticed, and interstitial glass base seems to be entirely wanting in nearly all the specimens. In this trachytic paste are many small hornblende prisms and needles, all of which are entirely altered to a fine-grained mixture of augite and opacite, and many small, colorless augite crystals either prismatic and broken or of irregular shape, some of which seem to be derived from the large altered hornblende phenocrysts. Magnetite is very rare in these segregations.

The not very abundant plagioclase phenocrysts seem to be identical with those of the surrounding rock, showing twinning lamellæ and carrying the same inclusions, though usually those of glass do not form a distinct "net." One group of large plagioclases includes numerous patches of brown biotite all of which are oriented alike (micropoikilitic structure), and a little biotite also acts as a mesostasis between the plagioclase crystals. The larger augite crystals, which are to be classed as phenocrysts, are quite abundant and do not differ materially from those of the surrounding rock. Some biotite crystals, brown in color and wholly altered, are also seen.

The hornblende which is present in abundance as phenocrysts, though it also bears much resemblance to that of the mother rock, calls for special description. The crystals are all prismatic and, where the original hornblende substance is seen, of the usual brown color, though rather darker in tone. In many of the fresh patches of unaltered hornblende are found narrow bands of much darker color. These bands, which even with the use of the highest powers are irresolvable, show the pleochroism of the regular brown hornblende, though modified by the greater depth of color. In hornblende sections cut normal to the vertical axis they lie parallel to the clinopinacoid, bisecting the obtuse angles of the cleavage lines, while in longitudinal sections (approximately parallel to $b(010)$) they cut the parallel cleavage lines obliquely in the direction of a positive orthodome. The angle, which is not quite constant, is in general 65°–70°, making the bands lie parallel to the plane $f(\bar{3}01)$. These bands are hence seen to represent sections, not of sheets, but of rods, similar to but thicker than those seen in the hornblende of a rock from Mt. Pagoni.

The alteration of the hornblende, however, is its most constant and characteristic feature. The crystals have all undergone a change, so much so that kernels of fresh substance are comparatively rare. In most cases they show a mass, or else a central core, of fine grains of black opacite embedded in a finely granular mass of augite and plagioclase. These occurrences show clearly

that the plagioclase grains are in reality products of the alteration of the hornblende and not particles derived from the groundmass which have penetrated between the augite and opacite grains. In the largest and most altered crystals this opacite core is surrounded by a border or frame of almost pure augite in the form of colorless prismatic grains, giving extinction angles of 36°, and their long axes parallel to the $\dot{c}$ axis of the hornblende, so that the ends of many of these hornblende pseudomorphs have a fringed or bearded appearance. In the less fresh specimens this augite assumes a greenish yellow color, when it resembles more than ever uralitic hornblende. This prismatic augite does not only occupy the border of the hornblende pseudomorphs, but in many cases penetrates the opacitic aggregate in irregular patches. Many of these altered hornblendes show signs of great mechanical disintegration since their alteration, patches and prisms of the secondary augite being seen to have been torn away from their original positions and scattered through the groundmass of the segregation. Küch (pp. 46, 176) observed apparently similar occurrences, though not in segregations, which he refers to a parallel growth of augite and hornblende. This does not seem to be the correct explanation, at least for the present case, and it is most probable that these borders of prismatic augite are due to causes similar to those which produced the opacitic and "augite-opacite aggregate" alterations of hornblende, forming a later and probably the final stage of these.

The occurrence of these alterations in the case of segregations in rocks where they also occur, while they are not found in the segregations in rocks containing fresh green hornblende, is very interesting, and contrary to what Küch and Belowsky observed in their otherwise very similar occurrences. The observation often previously made that only the brown hornblende is liable to this alteration is again confirmed, and this fact seems to be a fundamental one to adopt in any explanation of the set of phenomena. Judging from the present cases it seems certain that the alteration took place before the solidification of the groundmass, which would place the period of alteration of the hornblende

prior to that of the consolidation at a great depth of the magma forming the segregations. This seems at first sight to be at variance with the fact already noted in the case of the hornblende-augite-andesites, that many of the small groundmass crystals are still fresh; so that we seem driven to the conclusion that not only are the conditions under which the alteration may take place extremely variable, but that after hornblende has been formed and altered, a subsequent formation of fresh hornblende may occur. The final stage of the process is similar in physical structure, though chemically and genetically quite different from the final stage of the uralitization of augite, which we know to be due to the action of moisture, and it might be said that instead of hornblende being the stable form of augite, augite is the stable form of hornblende, at least of the basaltic variety.

In one of the segregations of Mt. Pagoni accessory olivine is present in large colorless crystals, of a bright yellow on the edges. While the crystals are of irregular shape they have been formed, as was to have been expected, prior to the formation of the hornblende or augite, both of which are xenomorphic with respect to it. Few of these segregations differ from the type just described. One from Mt. Pagoni seems to have solidified rather more rapidly than the above, as the groundmass is a colorless glass base, hyalopilitic through the presence of numerous plagioclase microlites. In this segregation the bearded hornblende pseudomorphs are especially well shown, and the plagioclase phenocrysts, which are very clear and show few twinning lamellæ, are much more numerous. The other (from Mt. Gaiapha) seems to have been originally very similar, but the groundmass is replaced by colorless calcite, which entirely replaces the glass and acts as mesostasis for the large crystals. Neither the hornblende nor the plagioclase phenocrysts of this segregation nor the surrounding rock in general show signs of decomposition, and it is possible that the calcite is rather a primary than a secondary constituent.

The second variety of segregations differs from those just described in two important respects; the hornblende is green and

the groundmass is vitreous. The groundmass is composed largely of a perfectly clear and colorless glass base, showing no perlitic cracks, in which lie small water-clear plagioclase crystals and skeleton crystals, either forked at each end or forming a hollow square, with some small hornblendes, apatite needles and, in the case of the Methana segregations, some small hypersthene prisms. Round vesicles or gas pores are also not uncommon. In a few cases this base is brownish in streaks and patches, the color being due to the presence of minute brown dust grains, and associated with these (in one specimen) are very many straight black trichites or minute club-shaped microlites often arranged radially. One segregation from Kakoperato, which is especially rich is these brown streaks, contains also many rounded granospherites, which have little or no action on polarized light. These frequently contain, as seen only under the highest powers, extremely small straight black trichites, in fan-shaped aggregates. As in the preceding variety there is no evidence of flow structure either in the groundmass or among the phenocrysts.

The hornblende phenocrysts are in the shape of needle-like crystals or prisms, elongated parallel to $\dot{c}$. When embedded in the groundmass they are automorphic, but are on the other hand generally xenomorphic in respect to the plagioclase, though the converse also occurs. Their color is, it has been said, olive green, and they show no signs of alteration. An exception to this must be noted in the case of one Kaimeni segregation, where they are yellowish brown and generally have an altered border.[1] This specimen shows the dust and black trichites in the groundmass in the greatest perfection, and the small hypersthene prisms are almost entirely altered to a brown or black substance. Large phenocrysts of colorless augite occur in small quantity in one or two of the specimens, but they are rare and call for no special mention except that they are always xenomorphic in respect to the hornblende.

The plagioclase phenocrysts are all automorphic, generally

[1] This enclosure, it must be remarked, is in a scoriaceous lava which shows many signs of decomposition, perhaps due to fumarole action.

giving long rectangular sections, and are mostly perfectly water-clear. They do not show many twinning lamellæ and occasionally have undulatory extinction, but are all certainly plagioclase. The extinction angle of 35° observed in one case indicates that they are anorthite, which is confirmed by the high percentage of CaO found on analysis (cf. Anals. 8, 11, Table I.). A few large stout plagioclase crystals are seen, the megascopic phenocrysts, which resemble those of the surrounding rock. They all show a core of glass network, or of fine plagioclase grains with very little glass, resembling the holocrystalline xenomorphic groundmass of some porphyries. These crystals often enclose flakes of hornblende.

In the reddish hypersthene-andesite of the Methone acropolis are found round, dark gray fine-grained segregations, which on examination under the microscope show no marked difference from the rock surrounding them. They also are hypersthene-andesites, with some accessory brown hornblende phenocrysts and many small hypersthene prisms in the vitreous groundmass, which shows a beautiful flow structure.

It is noteworthy that in all the segregations magnetite, except that due to alteration of the hornblende, exists only sparingly, it being entirely absent in one or two specimens. It is rather more common in those with green hornblende in rather large grains, which are more frequently found as inclusions in the hornblende than in the plagioclase. Zircon, on the contrary, is rather common in all the segregations as small colorless crystals, both included in the other minerals and in the groundmass. These masses show no evident signs of the action of the surrounding molten magma upon them (except in their rounded outlines), and in the enclosing rock itself no traces are to be seen in their immediate vicinity of any change in structure or composition.[1] The presence of glass base in them (also observed by Küch and Belowsky) is interesting and, inasmuch as it is impossible to conceive of the masses having preserved their

[1] For such contact phenomena in the case of enclosures, cf. DANNENBERG, Min. Pet. Mitth. XIV., 1894, pp. 17–94.

individuality and not being completely disintegrated during the violent movement of translation by the lava stream from a presumably great depth to the surface if some solid binding material did not exist between the large component crystals, we must suppose this interstitial matter to have solidified as glass (or trachytic groundmass) at a great depth. This groundmass, whether vitreous or holocrystalline, differs radically from that of the surrounding rock and so cannot be supposed to be due to penetration of the enclosure by the still liquid magma in which it lay. While such enclosed masses have been classed here and by others as endogenous enclosures in the sense already defined (p. 138), yet the presence of such a glass base tends to throw doubt on this view and makes it seem possible that we have here to do with fragments of an earlier lava flow, at present buried deep beneath the later superincumbent lava streams. This question will, however, be discussed at greater length later.

STRUCTURE AND MINERALOGICAL COMPOSITION.

Before we begin the chemical discussion of these rocks it will be as well to speak of one or two points in regard to the general structural and mineralogical characteristics of all the rocks described from this region. As regards structure, it may be said that megascopically the most basic rocks — such as the hypersthene-andesites and from a certain standpoint the segregations — are the most even-grained and show fewest phenocrysts, a porphyritic structure being more and more highly developed, and the size and abundance of the phenocrysts increasing, as a rule, with increasing acidity; the dacites on the whole standing in this respect (as well as chemically) at the opposite end from the Oros hypersthene-andesites. The chief exceptions to this general rule are most of the hornblende-augite-andesites of the Monastery District. To put it broadly, the difference may be expressed by saying that basic rocks are largely groundmass, while the acid rocks are to a much larger extent phenocrystic. Microscopically it is seen also that the groundmass of the dacites, while less abundant, is much

more vitreous than that of the basic andesites. The largely predominating groundmass of the hypersthene-andesites is made up chiefly of plagioclase and hypersthene lathes and augite crystals, with comparatively little interstitial glass base, while in the hornblende-augite-andesites the larger groundmass crystals are fewer in number (though still numerous), and the rather more abundant glass base is very thickly strewn with microlites, magnetite grains and "dust."

In the dacites, on the contrary, and in the more acid andesites, as those of Poros and Spasmeno Vouno, larger crystals are comparatively rare in the groundmass, which is highly vitreous and often typically, though not densely, hyalopilitic with occasional perlitic cracks. The tendency in the basic rocks seems to be toward forming larger crystals in the groundmass, while in the acid rocks the tendency is more toward microlitic development. An excellent illustration of this difference of structure as related to chemical composition is seen in the pyroxene-andesites of Mt. Kouragio and Mt. Chelona, the former containing 54.53 per cent. of SiO_2, while the latter contains 59.83 per cent. The groundmass of the latter is vitreous containing many microlites, but few larger lathes, while in the former the glass base is relatively much less abundant and the number of larger plagioclase and hypersthene lathes and crystals in the groundmass very great.

So that, in general, it may be said that in these rocks the more acid the rock the more vitreous the groundmass, the smaller and more microlitic the crystals in it, and the larger and more abundant the phenocrysts. To this rule there are, of course, exceptions, as seen in the hornblende-augite-andesites, since the chemical composition of the magma is only one of the many factors involved in the crystallization of rocks.[1] But inasmuch as all the rocks of this origin have solidified under quite similar conditions as regards pressure and rate of cooling, they being all massive (domal) eruptions, and stock, dike or sheet

[1] IDDINGS, Crystallization of Igneous Rocks, Bull. Phil. Soc., Washington, 11, 1889, p. 113.

occurrences not being represented, these factors are to a large extent eliminated, and the present occurrences offer a good opportunity for study of the relation of structure to composition. As regards this relation they are quite in accordance with Iddings' conclusion that "the basic magmas exhibit a much greater tendency to crystallize than the highly siliceous or alkaline ones."[1]

But it seems to me that the difference between them is not entirely one of simply greater or less tendency towards crystallization, but that this tendency in the two classes differs in *quality*, and that it is probable that further research will show that the highly acid magmas have a tendency to crystallize about comparatively *few* centers, the result being an eminently porphyritic structure, with a vitreous, felsitic, microlitic or extremely fine-grained holocrystalline groundmass, due probably to the rapid cooling of the still liquid groundmass magma; while in the basic rocks the tendency is to crystallize about very numerous centers, the result being a fine-grained rock with few phenocrysts and the groundmass containing many small crystals and microlites, but comparatively little glass base. It would follow from this that in these last rocks the transition between phenocrystic and groundmass crystals will be much more gradual than in the acid rocks.

Such a relation is clearly shown on comparing the basalts with the trachytes or rhyolites, where the generally porphyritic structure and vitreous or minutely crystalline groundmass of the latter is in striking contrast with the slightly porphyritic structure and groundmass full of small crystals in the former. That the same law probably holds good for the plutonic rocks as well is indicated when we compare the granites and diorites; where, as a rule, the former are much larger grained than the latter, the larger grains being the natural result of fewer centers of crystallization in a magma which was finally completely crystallized.

Such tendencies may be most closely connected with the

[1] IDDINGS, Crystallization of Igneous Rocks, Bull. Phil. Soc., Washington, 11, 1889, p. 107.

greater or less fusibility of the rocks in question, their fusibility being in turn directly dependent on their chemical composition. Lack of space, however, forbids further remarks on this subject, and the examination and elaboration of the suggestion made above must be left for another place.

Mineralogically the rocks of this region do not show, on the whole, very gradual transitions from one species to another, many of the groups being sharply separated from all the others, as in the cases of the hornblende-andesites and hornblende and biotite-dacites. On the other hand there is among the members of the pyroxene-andesite group a gradual transition from the augitic to the hypersthene end, and some other cases occur, as will have been noticed.

The basic rocks are decidedly more pyroxenic than the acid ones, and of the two members of this family present augite shows a decidedly greater fondness for the most basic rocks than the hypersthene, which is one of the main components of a large group of dacites; it will also have been noticed that the hypersthenic andesites are more acid than the augitic. Hornblende is the most prominent ferro-magnesian silicate of the acid rocks, the green being especially characteristic of these, while the brown variety is usually associated with augite. Biotite is not very abundant, but occurs in the most acid rocks, either alone or with hornblende. Magnetite does not show any well defined preferences, but in accordance with the law just enunciated it usually occurs in larger crystals in the more acid rocks.

CHEMICAL COMPOSITION.

The analyses[1] presented in Table I. were made for me by Dr. A. Röhrig of Leipzig, while Dr. H. Lenk of the University of Leipzig had the kindness to make the specific gravity determinations. Care was taken to select the most representative and least altered pieces, though in some cases it was impossible to find quite fresh specimens. The figures in small

[1] TiO_2 was determined as the residue left on volatilization of the silica with hydrofluoric acid. H_2O is the loss on ignition.

TABLE I.

Analyses of Rocks of Ægina and Methana.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2	54.86	59.93	55.46	55.87	54.53	59.83	59.94	56.38	61.29	64.06	55.87	64.83	62.90	55.83	67.34	70.81
	0.908	0.992	0.918	0.925	0.903	0.991	0.992	0.933	1.015	1.061	0.925	1.073	1.041	0.924	1.115	
TiO_2	0.05	0.96	0.21	0.01	0.96	0.01	0.02	0.33	0.65	0.18	0.16	0.08	0.18	0.32	0.46	0.07
Al_2O_3	23.08	16.99	16.76	18.74	13.06	17.82	18.40	17.48	17.68	15.25	22.40	17.60	18.29	18.96	15.96	11.82
	0.226	0.166	0.164	0.183	0.131	0.174	0.180	0.171	0.173	0.149	0.219	0.172	0.179	0.186	0.156	
Fe_2O_3	4.41	3.58	5.15	4.88	6.85	3.62	3.69	5.30	6.03	2.72	2.52	4.95	1.79	5.64	3.38	1.82
	0.028	0.022	0.032	0.031	0.043	0.023	0.023	0.033	0.038	0.017	0.016	0.031	0.012	0.035	0.021	
FeO	1.50	1.28	3.00	5.01	4.86	4.60	2.99	2.72	0.30	4.30	1.80	1.82	4.00	3.23	0.80	3.69
	0.021	0.018	0.042	0.089	0.068	0.069	0.042	0.038	0.004	0.059	0.025	0.025	0.056	0.045	0.011	
CaO	6.98	5.92	10.00	8.20	9.83	6.88	6.58	10.89	5.61	3.93	9.20	5.26	5.62	7.40	2.98	4.45
	0.125	0.106	0.179	0.146	0.176	0.123	0.118	0.194	0.102	0.070	0.164	0.094	0.100	0.132	0.053	
MgO	1.29	1.51	2.44	1.39	3.14	1.64	1.95	3.10	2.45	1.30	2.99	1.61	1.61	2.76	0.88	1.10
	0.032	0.037	0.060	0.034	0.078	0.041	0.048	0.077	0.061	0.032	0.074	0.040	0.040	0.068	0.022	
Na_2O	3.35	3.23	2.94	3.43	4.62	3.31	3.43	1.77	4.28	4.37	1.80	2.52	2.91	3.12	4.12	2.41
	0.054	0.052	0.047	0.055	0.074	0.053	0.055	0.029	0.069	0.070	0.029	0.041	0.047	0.050	0.066	
K_2O	1.48	1.55	1.95	1.55	1.59	1.23	1.67	1.38	1.38	2.78	0.39	1.53	1.48	1.17	1.66	0.96
	0.016	0.017	0.022	0.017	0.078	0.014	0.019	0.015	0.015	0.031	0.004	0.017	0.016	0.013	0.018	
H_2O	2.80	4.28	1.60	0.36	0.52	0.36	0.94	0.52	0.96	1.70	2.66	0.20	0.98	1.20	2.20	1.96
Cl.	0.0089			0.0071									0.0064	0.0018		
	99.81	99.23	99.51	99.45	99.44	99.30	99.61	99.87	100.63	100.59	99.79	100.40	99.77	99.63	99.78	99.09
Sp. Gr. 15° C.	2.503	2.327	2.610	2.769	2.687	2.635	2.440	2.468	2.440	2.352	2.268	2.539	2.464	2.647	2.462	

1. Hornblende-andesite, Mt. Stavro, Ægina.
2. Hornblende-andesite, Spasmeno Vouno, Ægina.
3. Hornblende-augite-andesite, West end of Mt. Chondos, Ægina.
4. Augite-hypersthene-andesite, summit of Mt. Oros, Ægina.
5. Augite-hypersthene andesite, Mt. Kouragio. Ægina.
6. Hypersthene-andesite, summit of Mt. Chelona, Methana,
7. Hornblende-hypersthene-andesite, Kaimeni Stream, Methana.
8. Hornblende-andesite, segregation in No. 7.
9. Hornblende-dacite, Anzeiou, Ægina.
10. Hornblende-dacite, Kakoperato, Ægina.
11. Hornblende-andesite, segregation in No. 10.
12. Hornblende-hypersthene-dacite, near Panagia, Methana.
13. Hornblende-hypersthene-dacite, Kosona, Methana.
14. Hornblende-andesite, segregation in No. 13.
15. Biotite-dacite, Kolantziki.
16. Andesite Tuff (silicified), Mt. Chondos, Ægina.

type show the molecular proportions of the several oxides and will be referred to further on.

From these analyses, which include all the prominent varieties of the region except the Poros andesite, it is seen that we have representatives of almost all the members of the andesite and dacite families, and that on the whole they are quite normal in composition. Leaving the segregations out of account for the present it is seen that the range of silica percentage is almost the complete one for the two groups, varying quite gradually from 54.53 (No. 5) to 67.34 (No. 15), or even 68.91 in the dacite of Kalamaki.[1] The line between the dacites and the andesites is quite sharply drawn, though the dacite of Anzeiou shows an abnormally low percentage of silica (61.29). The other dacites, though, show quite normal amounts, and the dividing line may be drawn at 61 per cent. of SiO_2,[2] the most acid of the andesites, that of Poros, containing 60.21 per cent. (according to Lepsius, *loc. cit.*).

The presence of chlorine in all the specimens in which it was tested for is of interest and analogous to results obtained elsewhere in volcanoes very near the sea.[3] Attention may here be called to the much smaller quantity of Cl. in the segregation (No. 14) than in its surrounding rock (No. 13). The H_2O is in quite large amount in several, and is more than can be accounted for by perlitic groundmass. All the specimens, however, except No. 2, seemed quite fresh.

While both of the analyses of hornblende-andesite (Nos. 1 and 2) can be quite closely paralleled by analyses of the same species from other localities, yet they show *inter se* great differences in their percentages of silica and alumina. The very low silica content of the Stavro rock is the more surprising inasmuch as on account of the presence of tridymite, green hornblende and biotite and on other grounds, a considerably higher amount of

[1] Lepsius in PHILIPPSON, Pelop., p. 603. The SiO_2 determination in the Sousaki dacite is not counted here as the specimen was not fresh.

[2] The analyses of KÜCH (op. cit. p. 78) indicate about the same limit, his most acid andesite containing 62.26 per cent. SiO_2.

[3] Vesuvius, Anals. of Haughton, in ROTH. Beitr. z. Petr., 1884, p. lvi. Etna, Anals. of Ricciardi, *Ibid.*, p. lxxvi.

SiO_2 was to be expected. The very large amount of Al_2O_3 is also very remarkable, it being the largest of the whole series; and, since calculation shows that the extra amount of Al_2O_3 in No. 1, over No. 2, if determined as SiO_2, would bring the percentage of the latter in No. 1 up to 58.46 (*i. e.*, nearly equal to that of No. 2), while the other oxides in the two are in closely similar amounts, it is feared that a mistake has been made by the analyst. On this account (though with some hesitation) I have decided not to use analysis No. 1 in the further discussion of these rocks. The mistake suspected does not, however, affect the other constituents and we find them quite normal, the alkalies low, with Na_2O greater than K_2O, and the lime, in accordance with the character of the plagioclase, higher than both together; while the iron oxides and magnesia present no special features of interest, except that the ferric oxide is much higher than the ferrous.

In all the pyroxene-andesites (Nos. 3–7) the silica is low, though considerably higher in the last two, which are from Methana. Alumina in the Mt. Kouragio rock (No. 5) is extremely low, but elsewhere quite normal. The iron oxides are greater in amount than in any other group, the ferric oxide being either less or only slightly greater than the ferrous, which is due to the abundance of hypersthene; in the hypersthene-free andesite of Mt. Chondos (No. 3) the ferric oxide is, on the contrary, much more abundant. They are all rich in lime and magnesia but poor in alkalies, the large amount of lime being due to the basic character of the plagioclase.

The acid dacites show a normal amount of Al_2O_3, but are much poorer in lime and richer in soda than the other groups which bears out the conclusions drawn from the optical examination as to the character of the feldspar. The comparatively large amount of K_2O in the Kakoperato dacite (No. 10) points to the presence of some orthoclase as has been already mentioned. They are, on the whole, rather rich in iron and magnesia for the group, and in two cases the ferrous oxide is greater than the ferric.

The segregations are all low in silica and alkalies but high in

lime and magnesia, with alumina and the iron oxides quite variable. But a specially interesting point is the comparison of their analyses with those of their surrounding rocks of which three examples are given. The most striking fact is that in all three the segregations are more basic than their hosts, in one case the former containing 8.19 per cent. of SiO_2 less than the hornblende-dacite which carries it. They are also notably richer in lime, the same case as above containing 2.3 times as much as its host. They are also richer in magnesia. In general they are poorer in alkalies, though this not so prominent, but there seems to be no fixed relation as regards the alumina or the iron oxides. These results, which are what we would have been led to expect from the microscopical examination and our previous knowledge of segregations[1], confirm us in the belief that we have in these masses to do with true segregations (endogenous enclosures) and not (exogenous) enclosures.

Mention has already been made of the fact that the rocks of the Stavro district, Mt. Oros, Mt. Kouragio and Mt. Chelona are extremely poor in, if not quite free from, segregations, while on the contrary the dacites (with the exception of the Kolantziki rock and the Poros and Kaimeni andesites are rich in them. Now on referring to the analyses it will be seen that the rocks poor in segregations belong to the more basic members, while those carrying many of them are quite or very acid. The rocks of the Monastery District seem to occupy an anomalous position in this respect, since they generally abound in segregations, while at the same time the only one analyzed (No. 3 from Mt. Chondos) contains only 55.46 per cent. of silica. It must be noted, however, that the Mt. Chondos rocks carry fewer of these masses than the rocks of Mts. Gaiapha and Dendros, and it is possible that analysis of these last will show them to be richer in silica than No. 3.

Leaving these rocks then out of the question, the poverty of the basic rocks in the basic segregations points, like the consideration above brought forward, to the conclusion that these masses are

[1] Cf. ZIRKEL, op. cit, II., p. 788.

in reality segregations and not enclosures. In accordance with the theory of the differentiation of magmas the large masses of basic andesites as well as the smaller segregation masses are the products of such a differentiation process, so that the later ejected acid products would carry up with them parts of the later more basic differentiation products (the segregations) still remaining behind, while the main andesitic masses were ejected before these last were formed. That such is the true explanation is indicated by the fact that the segregations are, relatively to the neighboring basic rocks, richer in lime and magnesia, poorer in alkalies, and containing at the same time either exactly the same percentage of silica or even less (cf. Anals. 4 with 11, 6 with 8 and 14).

Again, if the masses in question were merely fragments of earlier now buried lava outflows, it is difficult to understand why the later basic streams of Oros, and the rest did not carry up fragments when such contiguous outflows as those of Kakoperato or Mt. Gaiapha did do so.

As to the specific gravities it will be seen that the more basic pyroxene-andesites are considerably denser than the hornblende-andesites or the dacites, and that the enclosures have likewise a decidedly higher specific gravity than their enclosing rocks.

Order of eruptions.—It has already been mentioned that, though the evidence at present available is scanty, the eruptive center of Ægina shifted as time went on from the south to the north. If, as seems probable, this be true, we find that the eruptions began with pyroxene-andesites and ended with more highly acid hornblende-andesites, the order of eruptions being, on the whole, one of increasing acidity. The establishment of this relation is of some importance, and we shall see whether the other occurrences of the region bear out the above conclusion or not.

The most striking and conclusive case is met with in the Oros district, where the certainly later flank eruption of Anzeiou and Kakoperato are much more acid than the earlier main outflows forming Mt. Oros. A similiar relation also obtains in the

Stavro district, where the later Spasmeno Vouno erupted material is more acid than the Stavro rock since, even making the alteration in the SiO_2 percentage mentioned further back, we find the acidity to be less than that of the former. The main Methana eruption also points the same way inasmuch as the earlier eruptions are all much more basic than the later flanking dacitic ones. One remarkable exception which has doubtless also struck the reader must, however, be noted. At Kaimeni the site of the very last eruption in the whole region, we should expect to find, in accordance with the rule above, a quartz-bearing dacite, perhaps like those of the mainland to the north; whereas we find a hornblende-hypersthene-andesite scarcely varying in chemical composition from the much older eruption of Mt. Chelona,[1] a gentle reminder that in the present state of our knowledge of the laws governing the chemical constitution of rocks generalizations must not be pushed too far.[2] While this exception is striking, yet it does not invalidate the rule enunciated above, and which we may regard as established for this region, that the order of eruptions was one of increasing acidity. The relation of these rocks to one another in time is that most usually observed among the several possible cases.[3] A closely parallel series of eruption products, though on a larger and more complete scale, has been described by Iddings[4] as occurring in the Yellowstone National Park. It is unfortunate that no data are at hand for determining the relative age of the rocks from any one group of the localities whose rocks are described by Küch and Belowsky, since their comparison would be of great interest owing to the many points of similarity between their specimens and those described in the present paper.

[1] It may be recalled that in the Kaimeni specimens are found a number of quartz grains which are conspicuously absent from the Chelona rocks.

[2] As IDDINGS has pointed out (Orig. Ign. Rocks, Bull. Phil. Soc., Washington, 12, 1892, p. 178) such reversions to an earlier type of differentiation products are not at all unusual.

[3] Cf. ZIRKEL, op. cit., I., pp. 810 ff.

[4] Erupt. Rocks of Electr. Peak and Sepul. Mt., 12th Ann. Rep. U. S. Geol. Surv., Washington, 1892, pp. 577–663.

To return to the analyses for a few moments, it will be seen on examination that the rocks of Ægina are, on the whole, notably less acid than those of Methana; the main mass of Ægina (excluding such small eruptions as those of Anzeiou and Kakoperato) being made up of andesites with a silica content not exceeding 56 per cent., while a large part of Methana is composed of dacites with over 61 per cent., and the most basic rocks have not less than 59 per cent. or more. This difference is most strikingly shown on comparing such similar rocks as those of Mt. Oros and Mt. Chelona, they being both hypersthene-andesites of very similar mineralogical composition. Here we find that the silica percentage of the former is 55.87, while in the latter it is 59.83. A similar result is reached on comparing the analogous rock of Mt. Chondos with that of Kaimeni, the respective SiO_2 percentages being 55.46 and 59.94. It may also be noticed that the dacites of Ægina are less acid than the dacites of Methana. When we look at these facts in the light of the law above laid down it follows that, on the whole, the eruptive activity of Methana most probably belongs to a later period than that of Ægina; which conclusion is supported by the fact that the only known historical eruption of the region took place on Methana, as well as by the absence in the latter of andesitic breccia cemented by tertiary limestone, and by the general appearance of the two islands.

Iddings[1] has endeavored to show that, as a rule, "the order of eruptions for any complete series of igneous rocks is from intermediate to more and more extreme varieties" (*loc. cit.* p. 183), so that at the beginning rocks such as the andesites are poured forth while at the close the eruptions are of basalt and of rhyolite; the exceptions being explained as belonging to unfinished progress of differentiation and eruption. While the exceptions are numerous and often not explicable in this manner, yet, in many localities, this law does undoubtedly hold good, and it will be of interest to determine whether this law also applies in the region which is the subject of this paper, as

[1] Orig. Ign. Rocks, pp. 144 ff.

well as at the volcanic centers situated on the same fracture line.

If we adopt Iddings' view it would seem, as the same writer has suggested in the case of the South American volcanoes,[1] that the volcanoes of the Ægina-Methana region are comparatively young and have not completed their full course of differentiation. Whether this course will eventually be completed, or whether for some unknown reason they have ceased activity forever, and will never reach the basalt and rhyolite stage it is impossible to say, though the latter is decidedly the more probable, as has been mentioned above.

But it must be remarked (as was pointed out by von Buch many years ago[2]) that basalt is entirely lacking along the whole volcanic line from Nisyros to Kolantziki.[3] On the other hand, rhyolite is said to occur on the islands of Kos[4] and Milos,[5] though in the case of the latter, owing to imperfect description and lack of analyses, its occurrence is somewhat doubtful. In these two cases the volcanoes are most certainly extinct, but no indication is given as to the relative age of the rhyolite as compared with the andesites which compose the other eruptive masses of the two islands. The volcano of Santorini is not yet extinct,[6] and here, to judge from the not very numerous good published analyses (which, moreover, do not cover the various varieties completely) it seems probable that the order of eruptions has followed the same law as in our district, the earliest rocks (those of Balos and Megalo Vouno and Thera) having been either

[1] JOUR. OF GEOL., I., p. 169.

[2] v. BUCH: Phys. Besch. d. Canar. Inseln. Berlin, 1825, p. 359.

[3] Basalt occurs to the north at Samothrace (NIEDZWIEDZKI: Min. Pet. Mitth., 1872, p. 107) and near Persufli in Thessaly (LEPSIUS: Geol. v. Attica, Berlin, 1893, p. 169), which we may suppose to be on a westward continuation of the Asia Minor line running from Armenia through Afium Kara Hissar and the Katakekaumene to the Troad and Lemnos, along which we know basalt to occur.

[4] DOELTER: Verh. Geol. Reichsanstalts, 1875, p. 233.

[5] EHRENBURG: D. Inselgruppe v. Milos, Leipzig, 1889, p. 102. ROTH: Geol. II., p. 229.

[6] The crater of Giorgio Kaimeni was in a solfataric state when I visited it in the spring of 1893.

shown by chemical analysis to be low in silica or else described as anorthite lavas,[1] while the latest outflows of Giorgio Kaimeni belong to the most acid pyroxene andesites.[2] But here again we have no trace of either basalt or rhyolite. As will be shown farther on, the rocks of Nisyros are probably similar to those described here, but scarcely anything is known of them.

Taking all the above facts into consideration, viz., the permanently extinct condition of Kos and Milos, and the almost as certainly extinct condition of our region, the total lack of basalts, almost total lack of rhyolites, and the overwhelming preponderance of intermediate andesites shading into dacites or very acid pyroxene-andesites,[3] and the not very basic character of the segregations, we may conclude that, while Iddings' law holds good for this region, it does so only partially; in that as the eruptions proceeded the magma became more and more differentiated, but that this process of differentiation never reached (as far as we can prove positively from the evidence of erupted materials), and probably never will reach, the extreme stages of basalt and rhyolite, the limits reached here being in one direction andesite with about 54 per cent. of SiO_2 and in the other dacites or andesites with 68–69 per cent. SiO_2.

THE REGION AS A PETROGRAPHICAL PROVINCE.

The scope of this paper as well as lack of space forbid my entering here into a complete discussion of the characters of the whole Ægina-Nisyros fracture line, but some remarks may be made on its general characters regarded in the light of a "petrographical province." As has just been pointed out the larger part of the eruptive rocks along this fracture line are pyroxene-andesites, with smaller quantities of hornblende-andesites, which, as the magma becomes more and more differentiated, run into highly acid andesites or else dacites, with perhaps some rhyolite.

[1] FOUQUÉ: Santorin, pp. 334, 341. Cf. ROTH: Geol. II., 362.

[2] Cf. ROTH: Beitr. Petr. 1869, p. cxxiv.

[3] It may be here remarked that as far as the published accounts and my own observations permit me to judge the eruptions near Smyrna and Pergamon were likewise confined entirely to andesites, and they are now certainly extinct.

The whole line is an excellent example of a petrographical province, the prevalence of hypersthene and colorless augite, and probably also the predominance of bytownite and anorthite among the feldspars, with absence of orthoclase, being some of the characteristics. But much work remains to be done in this direction along the whole line before we can feel justified in describing it.

The mineralogical and petrographical characters of the Santorini lavas are so well known that nothing further need be said of them here in this respect; but from a chemical standpoint, while they were examined with great care by Fouqué, yet many of the analyses are so unsatisfactory, and they cover such a small number of the various occurrences, that our knowledge of them is still very incomplete.

From the short and not very detailed descriptions of Ehrenburg and Roth, cited above, it would seem that the augite, hypersthene, and hornblende-andesites of the Milos group closely resemble those of Ægina-Methana, even in small details such as the occurrence of the hypersthene, glass "net-work" inclusions in the feldspar phenocrysts, rose color of the quartzes, and so forth. Unfortunately Ehrenburg does not mention the color of the hornblende of the hornblende-andesites, and no information is vouchsafed us by either author as to the chemical composition of the rocks.

Again, Nisyros, since it was visited by Ross[1] in 1841, who spent two days there and gives a short account of it, seems never to have been visited, and certainly never described by a geologist. When Ross was there it was in a solfataric state, and he describes the crater, the lava streams flanking the mountain and forming promontories in the sea. He speaks of the lava as black and mentions much ash and pumice as strewing the surface of the ground, but from his account we can form scarcely an idea of the petrographical character of the rocks of the island.

In the course of some excavations at Platæa in Bœotia in 1889, however, I found fragments of large corn-grinders made of a

[1] Ross: Reisen auf den Griech. Inseln. Stuttgart. Vol. II. 1843, pp. 68–80.

dark lava, and similar objects made of the same rock were discovered during the excavations of the American School at the Heraion near Argos. The rock is dark gray in color, fine-grained and finely vesicular and shows a few small phenocrysts of hornblende and plagioclase, with one or two larger quartz grains. Under the microscope it is seen to be a hornblende-andesite with a hyalopilitic groundmass of colorless glass base and numerous plagioclase microlites showing flow structure, the rather abundant phenocrysts being chiefly yellowish brown hornblendes, altered opacitically on the borders, with some clear colorless augites and large plagioclase crystals, many showing a "network" core.

Microscopically it has a certain resemblance to some of the Ægina rocks, though neither megascopically nor microscopically is it identical with any of the rocks seen or collected by me at Ægina, Methana or Santorini, nor does it correspond to any of the descriptions of Doelter or Ehrenburg of the rocks of Kos or Milos. It seems then almost certain that it does not come from any of these islands. Now, Strabo[1] informs us that the island of Nisyros supplied the neighboring region with excellent millstones, so that it seems reasonable to suppose that the corngrinders found at Platæa and Argos (which were Strabo's millstones) came from Nisyros. If this be so it would go to show that Nisyros has been ejecting much the same sort of rock as the volcanoes further west on the same line, which is *a priori* to be expected. It is needless to remark that the above argument is of very little weight, and it is chiefly inserted to emphasize the slightness of our knowledge of the Nisyros rocks.

However, leaving aside for the present the other volcanic centers of the fracture line, let us examine more closely the rocks of our present region. For this purpose I have constructed the diagram of the molecular variation of their constituents as shown in Diagram 1. The molecular amounts of silica are given by the abscissas, the limits of the diagram extending from .850 to 1.150. The iron oxides are given as FeO. In the upper part the six

[1] STRABO: Geogr., X. 5–16.

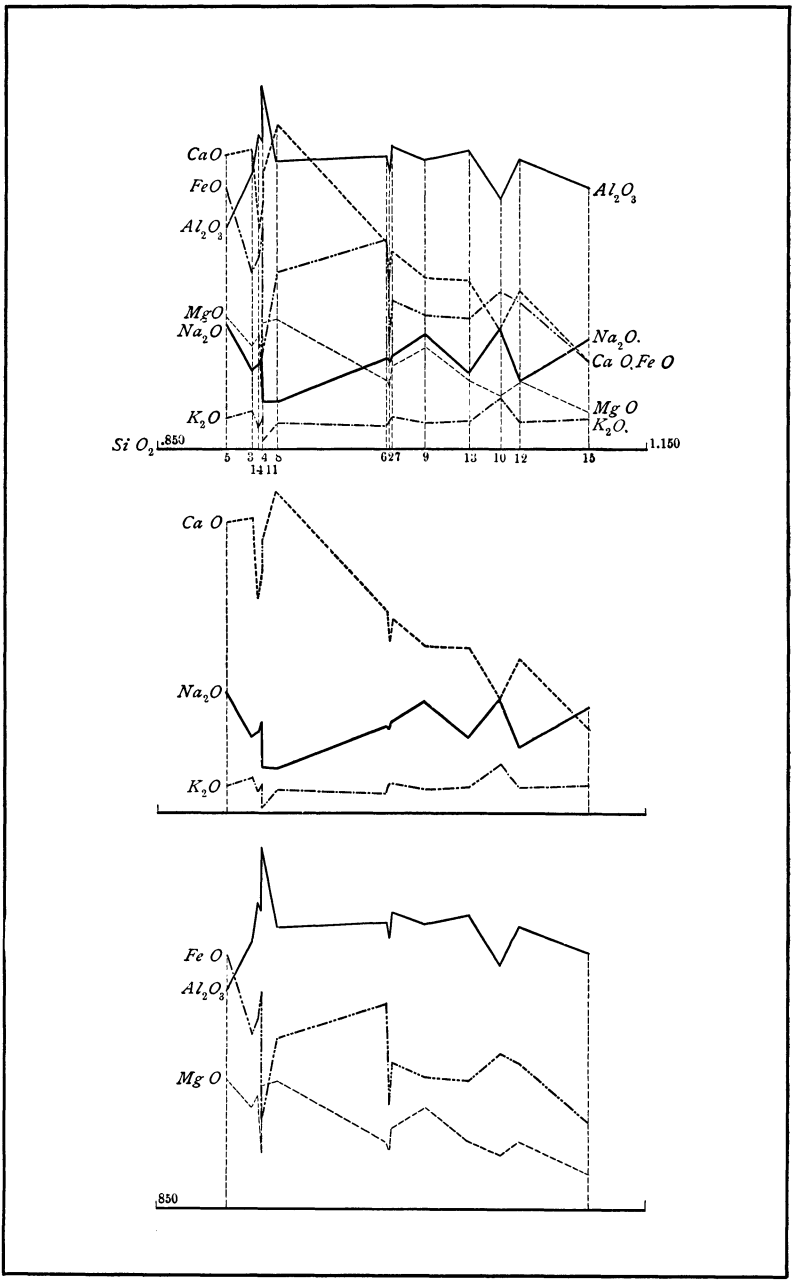


DIAGRAM 1.—Molecular variation of the rocks of the Ægina-Methana region.

main constituents (except SiO_2) are plotted together, while in the two lower sections they are given in two parts to avoid confusion and bring out more clearly some of the features of interest. I have arranged them somewhat differently from Iddings' previous diagrams, grouping together the CaO, Na_2O and K_2O, since these elements occur most prominently together in the feldspars, FeO and MgO occurring together in the ferro-magnesian silicates, and with these last two I have placed the Al_2O_3.

It is seen from this that alumina occupies a very high position though with considerable variation. In the more basic rocks it is surpassed three times by the CaO, which in this part of the diagram varies inversely as the Al_2O_3 does, while later the two lines run almost parallel, the CaO being considerably lower, and dropping a great deal as the SiO_2 increases. CaO and MgO run also approximately parallel, though the drop in MgO is less than in the other, and the inverse variation of Na_2O to both is well seen, especially with CaO and Na_2O in the middle section. K_2O follows the Na_2O line fairly closely, but its variations are always less than those of the other constituents, and it remains throughout in the lowest position, Na_2O being at least twice and often more than three times as great. It may be noted that in only two cases do the molecules of Na_2O and K_2O sum up more than those of CaO. Al_2O_3 and FeO also vary inversely at the very end, where there is a considerable drop in the FeO. MgO and FeO have quite similar lines, though at one point their variation is inverse, the latter maintaining an almost constant lower position. MgO varies on the whole inversely to K_2O and still more markedly so to Na_2O.

The relations of the segregations to their enclosing rocks is beautifully shown; the three segregations come also together near the basic end, while the three hosts come nearly together towards the acidic end; the richness of the segregations in lime and magnesia, their poverty in soda, and the variable character of the alumina and iron being well brought out.

Attention has already been called to the fact that the Ægina-Methana rocks show many points of resemblance to those of

TABLE II.

Analyses of Lavas of Santorini.

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	51.7	52.4	53.9	56.0	57.2	60.9	64.6	66.15	67.05	67.24	68.12	68.39
	.856	.868	.892	.927	.947	1.008	1.069	1.095	1.110	1.113	1.128	1.132
Al_2O_3	22.4	21.3	25.6	23.5	19.5	21.6	18.7	15.15	15.49	13.72	14.52	15.07
	.219	.209	.251	.230	.191	.211	.183	.148	.152	.134	.142	.148
Fe_2O_3	7.4	8.7	5.7	5.3	9.2	4.3	6.2			1.90		4.26
FeO								6.81	5.77	0.85	5.73	3.83
	.093	.109	.071	.066	.115	.054	.078	.095	.080	.036	.080	.106
CaO	10.4	11.8	6.8	6.7	5.7	4.2	2.8	3.48	3.48	3.46	3.68	3.19
	.186	.211	.121	.120	.102	.075	.050	.062	.062	.062	.066	.057
MgO	4.3	3.9	1.9	2.6	3.1	1.5	1.5	1.08	0.77	1.22	0.64	0.70
	.106	.097	.047	.064	.077	.037	.037	.027	.019	.030	.016	.017
Na_2O	3.4	1.8	3.4	5.5	5.2	4.6	4.7	5.22	4.65	4.90	4.96	3.86
	.055	.029	.055	089	.084	.074	.076	.084	.075	.080	.080	.062
K_2O	0.4	0.1	2.7	0.4	0.1	2.9	1.5	2.19	2.34	2.57	2.23	0.73
	.004	.001	.030	.004	.001	.032	.017	.024	.026	.028	.025	.008
H_2O									0.47	0.54	0.43	
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.08	99.94	100.59	100.31	100.03

1. "Anorthite Lava," Dike 20, Thera. Fouqué, Santorin, p. 332.
2. "Anorthite Lava," Dike 34, Thera. " " p. 332.
3. "Labradorite Lava," Dike 32, Thera. " " p. 333.
4. "Anorthite (?) Lava," Little St. Elias, Thera. Fouqué, Santorin, p. 334.
5. "Basic Lava," Balos, Thera. Fouqué, Santorin, p. 343.
6. "Labradorite Lava," Dike 49, Thera. Fouqué, Santorin, p. 333.
7. "Labradorite Lava," Dike 53, Thera. Fouqué, Santorin, p. 333.
8. Pyroxene-andesite, West May Island. Roth. Beitr. z. Petr., 1869, p. cxxiv. No. 11.
9. Pyroxene-andesite, Nea Kaimeni. Roth. Beitr. z. Petr. 1869, p. cxxvi. No. 12.
10. Pyroxene-andesite, Giorgio Kaimeni. Roth. Beitr. z. Petr. 1869, p. cxxiv. No. 2.
11. Pyroxene-andesite, Thera. Roth. Beitr. z. Petr. 1869, p. cxxvi, No. 14.
12. Pyroxene-andesite, Giorgio Kaimeni (?). Roth. Beitr. z. Petr. 1869, p. cxxiv. No. 10.

Colombia and Ecuador in their chemical composition, their structure, their mineral composition and in their segregations, even down to small details. It will hence be instructive to compare the diagram of the molecular variation of the present rocks with those of Colombia and the Andes volcanoes (especially the former), which Iddings has already published on pages 173 and 174 of Vol. I. of this journal.

On comparing the diagrams great differences are at once apparent. In the first place in our region the Al_2O_3 line, while on the whole the highest, is crossed at the basic end by both CaO and FeO, whereas in Iddings' diagrams it is far above all the others, and moreover drops notably more toward the acidic end than in the present diagram. In the South American rocks it runs much more parallel on the whole to CaO than in ours and is also markedly parallel to FeO, while in the Greek rocks the two are inverse throughout almost their entire course. Al_2O_3 and Na_2O are decidedly inverse in both regions, but in the South American rocks the two alkalies are inverse (especially in the Colombian rocks), while in Greece they are parallel. Another striking point of difference is the behavior of the CaO, MgO and FeO molecules which in both of Iddings' diagrams run close together and in the Andes rocks especially are much intertwined; in the Greek rocks on the other hand they run quite far apart from each other.

Further study of the diagrams will reveal many more points of dissimilarity, but those mentioned are sufficient to show that the rocks of the two regions are differentiation products of widely different magmas; in other words that the two petrographical provinces are fundamentally distinct. The same differences are also seen on comparing our diagram with that of the rocks of the Yellowstone National Park given by Iddings,[1] and which he remarks show a great similarity to those of the Andes rocks. The diagram here given may also be instructively compared with those rocks from other localities given in the same paper.

[1] Orig. Ign. Rocks, Pl. II. I was unfortunately unable to consult the paper by DAKYNS and TEALL (Q. J. G. S. 48, 1892, p. 104) quoted by him in JOUR. OF GEOL. I., 170.

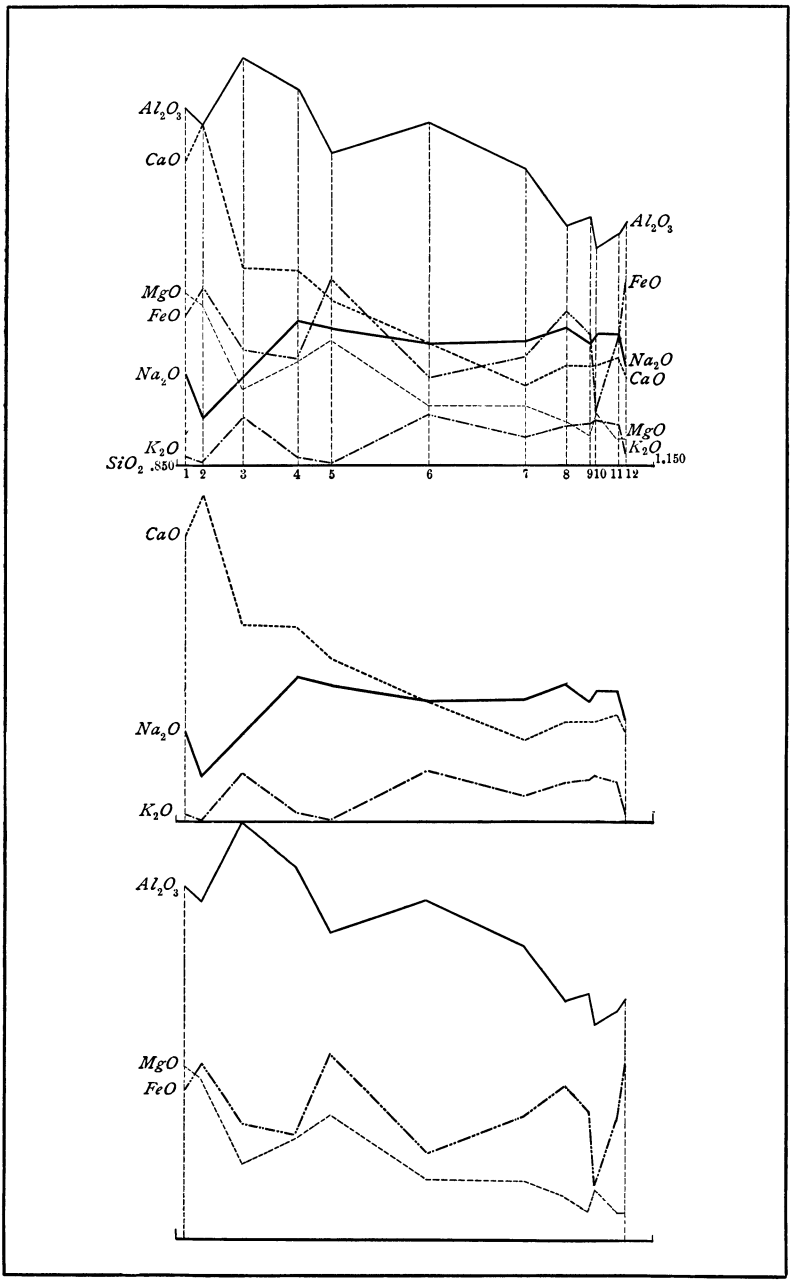


DIAGRAM 2.—Molecular variation of the lavas of Santorini.

Such differences in the fundamental chemical relations of the rocks of two widely separate regions are of very great interest especially, as Iddings has already pointed out,[1] as showing that the great bodies of magma beneath various volcanic centers or fracture lines differ radically from each other in chemical composition, and that the ideas of the consanguinity of rocks and the differentiation of magmas are true ones and based on deeper and more real distinctions than differences in mineralogical composition or the habit of the component minerals, which seems to have been the main idea in the minds of the originators of the term "petrographical provinces."[2]

In order to test this view further and set the reality of the term "petrographical province" more clearly and convincingly before the reader, I prepared Diagram 2, which represents the molecular variation of the eruptive rocks of Santorini, as given by the analyses shown in Table II. This diagram can only be regarded as an attempt at expressing the relations between the Santorini rocks, since Fouqué's analyses are most unsatisfactory (as is evident from an examination of them) and the probably more correct analyses quoted by Roth chiefly embrace the more acid rocks of Thera and the later eruptions. More analyses of the various lavas of this group are much to be desired and a diagram prepared from them would be much more conclusive than the present one.

Notwithstanding the unsatisfactory character of the analytical material the resulting diagram surpassed my expectations in regard to the similarity between the two districts, the two showing the same character in almost every respect, even down to details. The similarity will be evident at the first glance and the remarks on Diagram 1 will answer for Diagram 2, but to make it more emphatic I may call attention to a few points.

Na_2O and K_2O are in both beautifully parallel and with much the same habit, though in the Santorini rocks they drop a little at the acidic end, which, it must be remembered, is slightly higher

[1] Orig. Ign. Rocks, p. 135.

[2] VOGELSANG, Z. d. d. Geol. Ges. 1872, p. 507. JUDD, Quart. Jour., Geol. Soc. 1886, p. 54.

here than in the other.[1] CaO and Na_2O are beautifully inverse in both, except at the acidic extremity on Santorini where they both drop slightly together. They also cross in these rocks, soda becoming higher than lime at this end. FeO and MgO show the same kind of parallelism, and both are inverse toward Al_2O_3 throughout nearly all their length, but with the parallelism at the acidic end (especially between FeO and Al_2O_3) well shown in the two diagrams. The inverse variation of Al_2O_3 and CaO at the basic end and their parallelism toward the acidic end is well marked in both. But the above are sufficient, and further examination will only bring out more clearly the extremely similar character of the two lavas.

It would be most interesting to draw our conclusions from an examination of the diagrams given as to the character of the original magma, but it will be better to wait until a more satisfactory diagram can be drawn for Santorini with, if possible, one of Milos and Nisyros. By studying such a group of diagrams from a well defined volcanic fracture line the conclusions we might arrive at would be more valuable than those derived from less complete material. It may be worth remarking though, that, judging from these two examples, we can assert with much confidence that the rocks of Milos and Nisyros will be found to furnish diagrams resembling in their main features, if not in details, those given in this paper; that their general petrographical characters will be found to be very similar to those of the Ægina-Methana region, and also that the so-called rhyolite of Milos is in reality a dacite.

In conclusion, I may say that the two diagrams given here are sufficient to prove conclusively that not only do the eruptives of Ægina-Methana and Santorini belong to the same petrographical province, *i. e.*, are derived from the same main body of magma (which was *a priori* to be expected), but that this petrographical province has a magma quite different from that of the

[1] Compare the K_2O lines of these diagrams with those in the diagrams of the rocks of the Andes and the Yellowstone National Park, where the most acid rocks are rhyolites.

Andes, which was *a priori* not to be expected, since their solidified differentiation products (the lavas) so much resemble each other when examined individually by the usual petrographical methods. From this point of view such a comparison as has been here attempted is of special interest as going to show that the various bodies of magma beneath the earth's crust which supply the different volcanic centers are not identical,—parts of only one large interior mass,—as some have maintained who base their opinion on the superficial resemblance; though future research may show that these separate bodies of magma are themselves differentiation products of one original magma mass. But only a beginning has been made in the investigation of the differentiation of rock magmas, and, with Professor Iddings, I must put in a plea for fuller sets of analyses of the eruptive rocks from the various volcanic centers of the globe, as only such complete sets can furnish the data requisite for solving some of the problems that confront us.

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